Digester Selection and Operation for Heybeli Island

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Abstract

The Heybeli Digester project originated with Sema Alptekin in her personal research and was incorporated into a Senior Project opportunity at California Polytechnic State University, San Luis Obispo. The aim of this project was to select and design a plan for the use of a digester for the island of Heybeli, Turkey. The objective of this plan was to incorporate economic, social, and environmental justifications to evaluate if a digester would be a benefit to the community.

Systems Engineering analysis is a vital tool when working with complicated projects that include multiple systems interfacing with one another. Through the use of Systems Engineering analysis, requirements were formed that were then used to generate alternatives using current viable digester technologies. The feasibility of each alternative was determined by a number of factors deemed necessary to make a viable and responsible digester system: cost, environmental effect, and the social effect.

The main deliverables of this project was a digester model that incorporated gas use and fertilizer allocation. Additionally, a cost analysis of the different alternatives is presented along with environment impact in determining the optimal solution. The cost analysis takes into account material cost, maintenance cost, logistics cost, and operational cost. While the environmental impact is broken down into captured kilograms of greenhouse gases saved from entering the atmosphere.

There are five alternatives that are formulated in order to determine the best digester system. A variety of information is presented in this project for the reasons in coming up with each of the solid alternatives. They are shown through a cost breakdown and in a discussion of the positive and negative points of each. There are several assumptions in the creation of these alternatives. First, that the animal waste supply will be a stable for the next 15 years which is the proposed life cycle of the project. Second, the volatile solid amount of the animal waste meets the standard averages of horses around the world, which would need to be confirmed with a test on the island.

The selected alternative was a full scale Plug Flow Digester that uses the gas for a generator that converts the gas to electricity. The electricity use assumed to cover the use of heating and lighting the local stables which the horses are kept with the substantial overflow being left to the determination of the local community. The cost of this system is $168,579 with payback time of seven and a half years and IRR of 10.5%. The environmental benefit is 120,000 kg of greenhouse gas that is being preventive from being released into the atmosphere.

Introduction

The years of 1995-2006 were the warmest years in the world according to the Intergovernmental Panel on Climate Control. 60 percent of the world population must live on only 6 percent of the world income. Half of the world lives on two dollars a day or less (Yunus, 2007). Deforestation due to fuel wood removal contributes approximately 5 percent annually and by 2030 only 10 percent of the Earth's rainforest will be left. Due to the Increasing awareness of Global Climate Change and the current level of poverty in the world there is a responsibility to improve the globe now more than ever there is the need. The need for social business, business that take the community and the environment into consideration when defining how the company plans to do business, is now more necessary than ever before. Nonprofit organizations, The World Bank and other social organizations have spent millions of dollars and yet still have had limited success. This project presented the real opportunity to tangibly fight all the previously listed threats in a community of need.

Overview of the Project

Dr. Sema Alptekin presented the project idea of building a biodigester on an island off the coast of her home country Turkey called Heybeli or Heybeliada. This island, along with many of the other islands in the Princes Island Chain, does not allow motor vehicles and therefore most of the transportation on the island is done by horse carriage. Due to this large number of horses there is a large amount of horse waste being produced and possibly polluting the water supplies due to the presence of parasites and pathogens in the animal dung along with added responsibility of disposing the waste. Simply using the waste as fertilizer on the island will pollute the water and may transmit diseases lowering the quality of health on the island. The construction of a biodigester would alleviate the island of the problems along with contributing back to the community some added benefits. The byproduct of the biodigester would be methane gas, a biogas that can be used as an energy source on the island.

Problem Statement

This project will analyze the island and determine if a biodigester would be worth the investment for the island. Of particular importance to the project will be trade study for the decision of which type of biodigester best fits the current situation on the island, as they range in size, cost, biogas yield, solid concentration of the input which depends on the animals available on the island and finally the amount of waste product available. To get an idea of where Heybeli is located look at Figure 1: Hebeli Island is locatedat the A below.

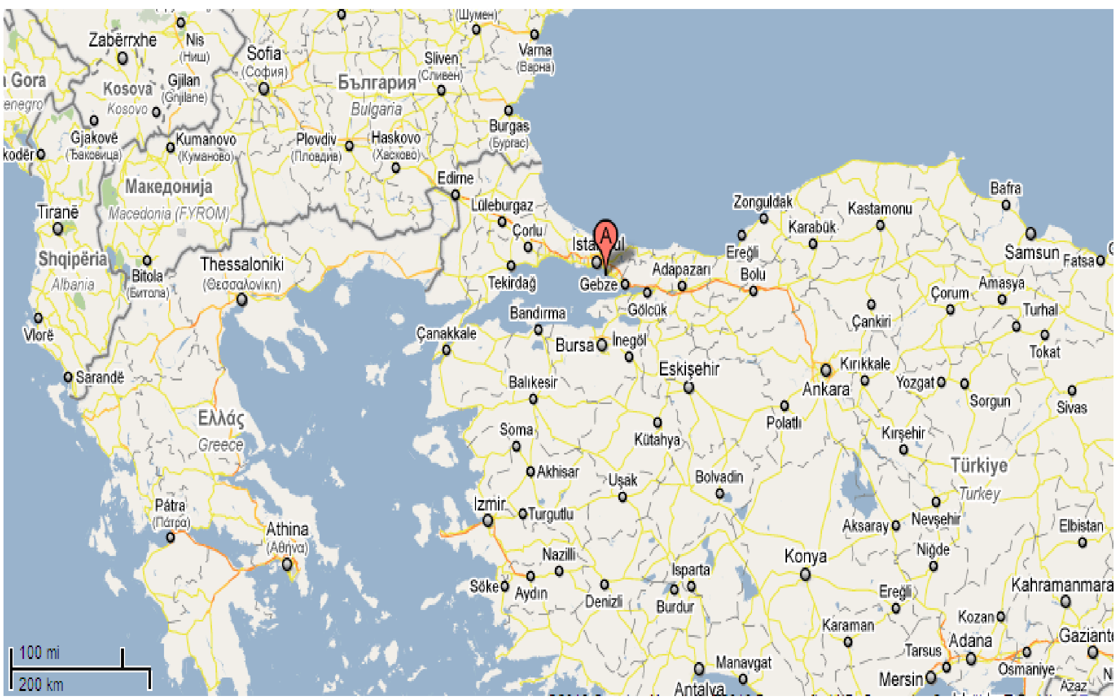

Figure 1: Hebeli Island is locatedat the A

The biodigester also needs to be designed with the consideration that it will be operated and maintained by the local population. The project will also take into how the biodigester will be constructed. A plan needs to be created that includes a supply chain that will function with the added challenges that arise with working on an island that does not allow motor vehicles including airplanes. A fully allocated cost will be generated to determine the overall cost of the project. One of the largest issues may be securing funding for the project and the different alternatives that will be investigated. Another issue that will be taken into account is the use of the produced gas and how that gas can have the most utility for the island. Dr. Alptekin initially proposed the gas could be distributed and used in cooking; a larger investigation will look in that option as well as other uses of the gas to ensure the maximum benefit as well as ensuring the option chosen is feasible.

Relevant Course Work

There are a number of courses that have aided to our project. Supply Chain and Logistics Management was a vital course to the project. Supply chains for the initial construction and for the disbursement of the methane gas required knowledge gained from this class.

A Systems Engineering approach was used to provide analyses on our customers' needs and required functionality of the life cycle of our project. A design alternative matrix can be used from System Engineering to help in the selection of the best alternative solution that will be presented. Furthermore Systems Engineering will provide both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Engineering Economics will also factor in decision for the best solution of biodigester. It will help aid in economic analysis portion of this project. Human Factors Engineering is important in designing the biodigester such that it will be easily used by the people of Heybeli. It can also be used to help fully understand the needs of the people. Project Management will be of use throughout the project in each phase. The class Industrial Cost and Controls will be used in generating a fully allocated cost for the project.

Background

The biodigester for Heybeli Island started at California Polytechnic State University, San Luis Obispo during the school year 2009-2010. Starting as Dr. Alptekin's personal project, it ballooned into a Senior Project along with the help of the club Engineering Without Borders. The initial objective of the senior Project was to learn more about international development opportunities that are presented when combing Industrial Engineering with focus of providing for underprivileged communities.

Dr. Alptekin was born in Turkey and goes to Turkey during the summer months annually as a vacation spot. During her recent trip she has established a relationship with the local community on the Heybeli Island and has come to recognize the area of opportunity that is presented by several factors. While the island is featured as a touristy destination the local population is around 7,000, and those that stay through the winter months live very simple lives.

Figure 2 Heybeli Island

Heybeli Island has a prohibited ban on the use of motor vehicles on the island which results in transportation and labor being dependent on horses. The island has approximately 100 horses which produce a significant amount of waste per day. Being a small island this presents a health and logistics problem of what to do with the waste matter.

The goal of this project is to create a higher level of living to the local people on Heybeli Island who live on the island year round. Alongside that goal, is the goal to develop a plan for implementing digesters that can be developed to reach not only the people on Heybeli Island but impoverished communities around the world.

An additional benefit of the biodigester is that 90% of the protozoa, cysts, and disease-causing bacteria such as E. coli are killed. The waste matter that is left after gas production is a high quality fertilizer that can be used safely on food crops. In result villagers can save money that they would normally pay for fertilizers. The removal of the majority parasites and pathogens leads to less pollution of water supplies and reduce the direct contact of animal waste. Also, with the waste solids being eliminated in the digestion process, the odors are reduced to an almost undetectable level resulting in an improved quality of life for the citizens.

A prototype digester is currently being designed at California Polytechnic University with the assistance of the Engineering without Borders (EWB) club. EWB plans on using their biodigester for their Thailand project. A digester is a device that produces methane gas through the action of anaerobic bacteria operating in a closed container. Inputs to the biodigester can be any organic material, but are usually some form of waste such as animal manure, sewage or crop residues.

Existing Digesters

Plug-flow

The Plug Flow is the most common form of digester in America; it incorporates the simplicity of design while still achieving results. Plug-flow digester design can be easily recognized by their length to width ratio of 5:1 which creates a long tubular shape (Goodrich, 2005). Manure needs to be collected daily and placed in the digester container. Each day a new “plug” of manure is added, slowly pushing the manure down toward the exit. The size of the plug flow system is determined by the amount of manure that is available which in turn decides the size of the daily “plug.” As the manure moves down the container it decomposes and produces methane that is trapped by the flexible cover. The expandable cover works to store the methane gas in addition to maintaining the optimal temperature for methane production. The optimal temperature for Plug-flow digesters usually operate at the mesophilic temperature range typically between 15 and 40 °C (Lusk, 1998). Plug-flow digesters require a mixing pit which is vital to the operation as it maintains the total solid (TS) concentration to a range of 11%-13% by the addition of water.

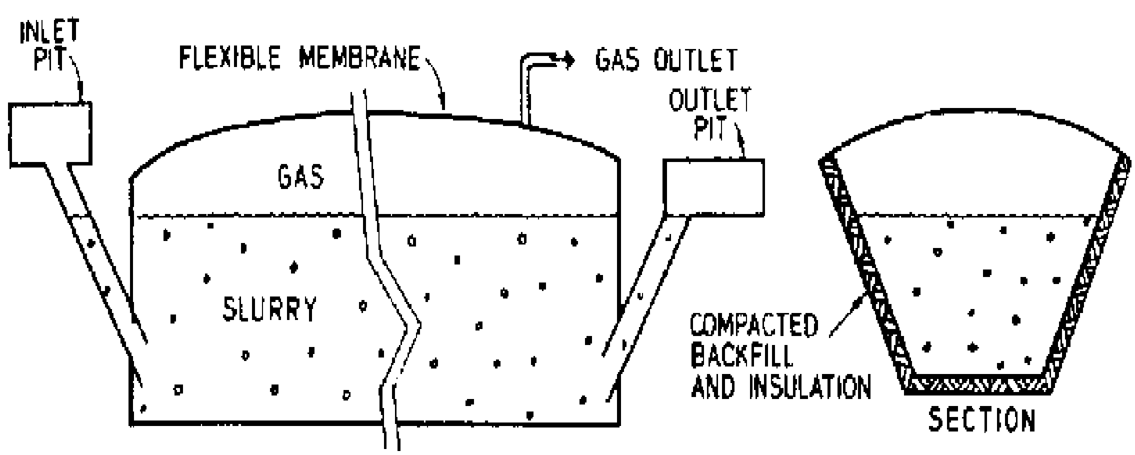

Figure 3. Basic Design of Plug Flow Digester (Marachaim, 1992)

Covered Lagoon

The covered lagoon digester is argued as perhaps the simplest digester system (Goodrich, 2005) but turnoffs to this system is that it is the one with the least energy output and has the most potential for complications. A basin is built in prepared soil and a layer of insulation is put down. Like the Plug-Flow digester, a cover is put over the lagoon to trap the methane production. The manure is heated before it is put into the lagoon. It's very important to have an insulated cover over the lagoon as it will keep the heat in during the winter months and allow the digester to keep producing biogas. Controls on this system are much less than other digester designs. The location selected for this design is very important as it has a much greater chance to fail in a cold climate as the lagoon won't keep the mesophilic temperatures needed for optimal biogas production.

Figure 4 Covered Lagoon (Lusk, 1998)

Fixed Dome Digester

Fixed Doom Digesters are used primarily in China where the focuses for the digesters are for odor control and waste management. The fixed dome digester is by far the most common digester type in developing countries (Nijaguna, 2002). This reactor consists of a gas-tight chamber constructed of bricks, stone or poured concrete. Both the top and bottom of the reactor are hemispherical, and are joined together by straight sides. The inside surface is sealed by many thin layers of mortar to make it gas tight. The digester is loaded daily or multiple times daily. There is a manhole plug at the top of the digester to facilitate entrance for cleaning, and the gas outlet pipe exits from the manhole cover.

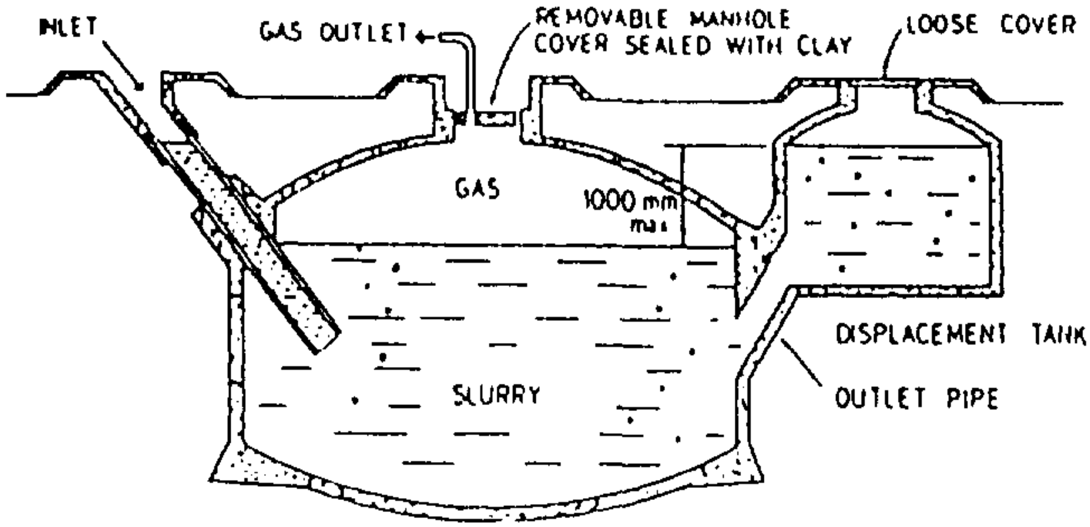

Figure 5: Basic Design of Fixed Dome Digester (Marachaim, 1992)

Floating Dome Digester

The Floating Dome design is primarily prevalent in India. Those most commonly constructed are of 6 and 8 m^3 gas production capacity. The digester is designed for 30, 40 and 55 days' retention time: the longer retention time are for cooler locations, while the shorter retention times for the hot locations.

Essentially there are four components to a floating dome digester: the digester tank, the floating dome, the influent chamber (feed pit) and the effluent chamber (outlet pit). The digester tank consists of a concrete base with concrete block walls. On one side of the tank, a pipe enters from the influent chamber; on the other, a pipe exits to the effluent basin. Cast into the tank's concrete base are three protruding rebar posts, which align with three PVC tubes constructed into the floating dome. The alignment of these two sets of parts ensures that the dome floats straight up and down within the tank. The floating dome consists of a galvanized iron and sheet metal frame, covered in impervious fiberglass. The dome is the storage vessel for the gas produced. As gas generated during anaerobic digestion, the dome floats upward. As gas is used, the dome recesses downward into the tank. The influent and effluent basins are also constructed of concrete block with a concrete base. The water/waste mixture is added to the system via the influent basin; digested liquid exits via the effluent basin.

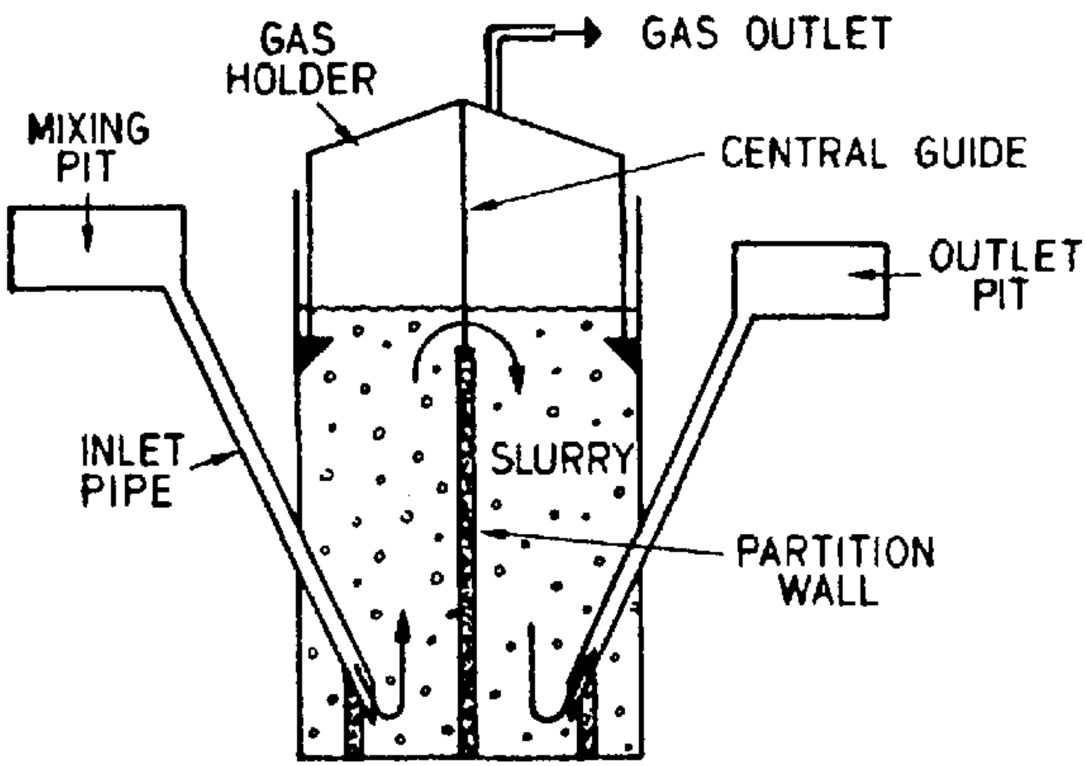

Figure 6 Basic Design of Fixed Dome Digester

Batch Digester

The current state of batch digesters requires multiple digesters usually above 20 to insure constant supply of biogas. As the name suggest batch digesters operate in lot increment where one load or “batch” is loaded into the digester and the full retention time is required before another load can be added. As one of the most successful biogas programs using batch systems has been that of Maya Farms in the Philippines and they had to use 30 digesters to insure the steady supply desired (Marchaim, 1992). As evident from the description of anaerobic digestion up to now, the "Batch" system is inefficient, but cheap to build.

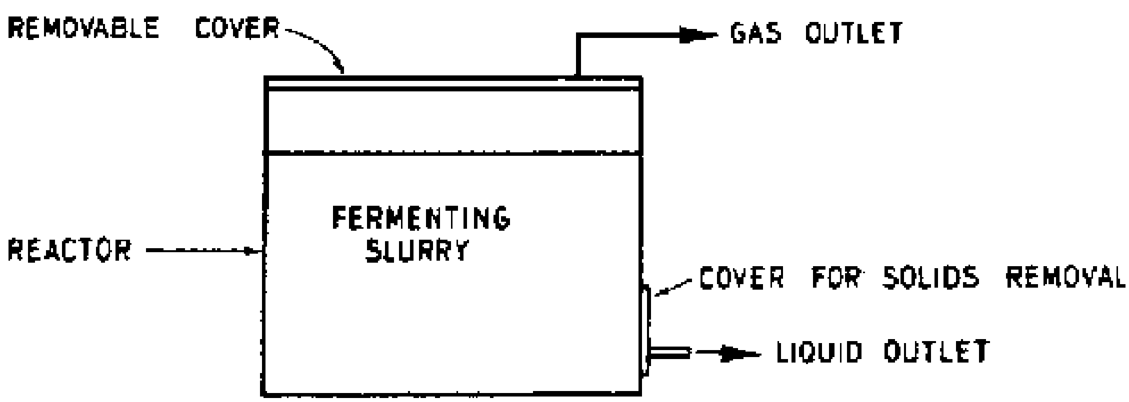

Figure 7: Basic Design of Batch Digester (Marachaim, 1992)

Literature Review

Below are the sources and information that helped guide the formation of this project. Each section specifies how that source was used in conjunction with our project.

System Engineering Management (Blanchard, 2008)

System Engineering is a handy tool in approaching broad problems that have multiple complex systems interfacing with one another. This book outlined system tools in which to approach problems at varying levels of the solution. First, breaking the problem down into appropriate requirement that meet the customer needs. Second converting those requirements to concrete quantitative numbers with which alternatives can be weighed against to choose the optimal solution.

Anaerobic Digester Systems for Mid-Sized Dairy Farms (Goodrich, 2005)

The success rate of installed systems has been very high for current engineering and equipment supply companies. The current ventures have supplied large margins of profit even for medium sized farmsteads. This report by AgStar details the pros and cons of the current varieties of biodigesters that are currently available. This information will be used to conclude which design for the biodigester that will be utilized in Heybeli Island for our project.

Good practice in QUALITY MANAGEMENT of AD residues from biogas production (Seadi, 2005)

The output in the biodigester process after going through the system is slurry, a watery material that is rich with nutrients. Seadi in his article discusses the uses and benefits that can be found through the utilization of this material. The buildup of toxins in the waste material is discussed in this article which raises the issues of quality management in the disposal process of any toxic effluent that is an output of the digester. A system of analyzing toxic and useful outputs of the digester will have to be established.

Animal Manure as One of the Main Biogas Production Resources: Case of Turkey (Tatlidil, 2009)

Renewable energy resources are becoming more prominent and important in today's world with the depletion of the finite resources. This article gives a good account of Turkey's current trend of going toward the biogas renewable energy industry. The article lays the groundwork for the growing acceptance in Turkey for alternative energy sources and how they're being used. It will be vital for the success of this project to work with the Heybeli Island community and make them a joint partner in this project since without their support this project eventual implementation will be unsuccessful. This article gives a general sense of the culture of Turkey and their acceptance to similar designs since the distance to the islands prevent direct observation.

The influence of temperature and total solid concentration on the gas production rate of a biogas digester (Dewan, 2004)

The desired temperature and the solid to liquid concentration of the biomass needs to be determined to provide the optimal results. The animals that occupy the Princes island regions are predominately horses which have a higher solid concentration in their fecal matter than the standard biodigester usually operates with. Thus with the results of this study which show a total solid concentration of 8% is optimal, will have to be integrated into the design of the system.

Methane Recovery from Animal Manures the Current Opportunities Casebook (Lusk, 1998)

The article provides an additional pro's and con's of the three major designs of digesters which is used to select the design used in our project. Data is given for the estimated gas output of pounds per biomass that is input into the system based on the design selection. A detailed description of the workings and blueprint of the structures that are incorporated with each separate digester design are given which can be then turned into a bill of materials that will be used in the supply chain analysis.

Biogas production with horse dung in solid-phase digestion systems (Kusch, Oechsner, Jungbluth, 2004)

In agriculture, slurry-based liquid-phase digestion is widely applied today, but digestion with elevated total solid (TS) promises further growth in the output of biomass. With the use of Horses in Heybeli an elevated TS is almost unavoidable without using some form of mixed digester which would significantly raise capital cost so further study in the use of higher TS concentration will be looked into. This article gives a detailed analysis of the use of horse dung and the optimal energy production that can be produce with that form of slurry. The total methane potential of the horse dung was determined to be 277 L_N CH4/kg.

Anaerobic Digestion: Biology & Benefits (Wilkie, 2005)

Wilkie presents an excellent overview of the benefits resulting from anaerobic digestion which includes: odor control, waste treatment, pathogen reduction, nutrient recovery, and greenhouse gas reduction.   This is in addition to the benefit of energy production through methane gas. Each of the benefits of anaerobic digestion is will be used in determining the final solution from our proposed solutions.

Special Topic Forum on Sustainable Supply Chain Management: Introduction and Reflections on the Role of Purchasing Management (Krause, 2009)

The company is defined by its supply chain, so if the supply chain is not sustainable then the company as a whole cannot be sustainable. Having a sustainable supply chain is important to the company because it takes care of all of the company's employees and suppliers around the world. If the supply chain is sustainable then the local economies of all the places the company draws resources from are supported. The article tells the history of supply chain starting when it was still called purchasing.

Kraljic's model reformed the concept of purchasing by utilizing the company's buying and bargaining power. Items were categorized into strategic, leverage, bottleneck and non-critical items each needing a different approach to reduce costs. The article then details the difficulties to ensure that a company's supply chain is in fact sustainable.

For strategic items an additional need for innovation in new product development as well as ensuring the supply chain partners emphasize sustainability. For leverage items, packaging suppliers for example, it is important to emphasize the use of recyclables and material reduction. For bottleneck items, sustainability may seem problematic; the emphasis should be on promoting industry wide sustainable standards. For noncritical items like office supplies, careful supplier selection and retention need to be looked at.

Food for Thought: Social Versus Environmental Sustainability Practices and Performance Outcomes (Pullman, 2009)

In the past a sustainable supply chain generally focused on environmental practices. In the article analysis on the food industry shows that an expanded view to include both environmental and social elements is necessary. To date there has been very little on research on the topic. Sustainable business should and do provide benefits to the economic bottom line especially for private or smaller companies to use as a competitive strategy. The article also addresses all the different opportunities for research that would greatly contribute to the field of social and sustainable business practices.

<u>Handbook of logistics and supply-chain management</u> (Brewer, 2001)

This handbook goes over the full spectrum of Supply Chain Management. The old economy was one that found its competitive strategy and guarded it with their lives. However in the new economy, transparency in vital throughout the supply chain and that access to information can give both the supplier and the company the advantage of avoiding the pitfalls in supply chain such as the bull whip effect where demand is distorted throughout the supply down to the supplies, suppliers. The article discusses the logistical difficulties that arise in a globalized economy and the different methods of measuring performance. The insights and difficulties involved with the transportation and logistics specific to the European region as well as the North American region are each defined as well as the international region. Supply Chain Management integrates such diverse interests as inventory planning, manufacturing operations and consumer behavior with intercorporate strategy, global information technology architectures and stochastic optimization modeling.

Creating a World Without Poverty (Yunus, 2007)

Muhammad Yunus explains that today's capitalistic economy is thriving yet the wealth disparity gap is larger than ever. Half the world lives on less than two dollars a day for survival. The free market only takes advantage of the impoverished and the government has shown to be very ineffective in providing change in this trend of poverty. Nonprofit organizations have formed but the challenge creating a world without poverty is too much. Yunus describes how each of these sectors can be more effective but Yunus focuses on the social responsibility on corporation. Millions of people are informed on corporation's action in the third world and this information has led them to choose more socially responsible corporations.

Yunus then describes some case studies which he has been a part of that have effected change in different impoverished nations. One such study describes the joint venture between Grameen Danone and the people of Bangladesh. They built a yogurt factory in Bangladesh that was solely employing the people of Bangladesh. Originally Grameen Danone had planned to distribute the yogurt using trucks transporting the yogurt to each individual city. Yunus advised using the Bangladeshi women who already traveled in between cities instead. This was not only cheaper, but empowered the people. They also built a farm in Bangladesh so that the milk used in the yogurt factory would provide even more people jobs and used a biodigester on the farm used for lighting and cooking. The Grameen Danone factory is not some distant corporate behemoth. It is a friend of the community and an integral and natural part of its social eco-system.

Thanks, but No Thanks: The Other Face of International Humanitarian Aid

(Mikolajuk, 2005)

The article describes the abuse of funding and details the importance of monitoring the government use of financial relief, emphasizes the importance of accountability and transparency in any organization and shows the necessity of long term solutions instead of simply sending quick relief.

International Nongovernmental Organizations and Deforestation: Good, Bad, or Irrelevant? (Shandra, 2007)

Some scientists have predicted that unless significant measures are taken on a worldwide basis, by 2030 there will only be ten percent of Earth's mature tropical rainforest remaining. Non government organizations can make a large impact in deforestation and the article outlines some different ways that non government organizations can do that.

Design

In the following section is a review of the requirements of the project, in addition to the deciding factors for the alternative models; these tools will be used to determine the best model quantitatively.

A system engineering technique was used in approaching the problem. The overall approach can be seen in **Figure 8**. All steps of the process can be found in this report outside of the construction and system operation. This report will provide a complete economical analysis of multiple alternatives that will be presented but actual construction and operation will end up being the decision of the citizens of Heybeli Island.

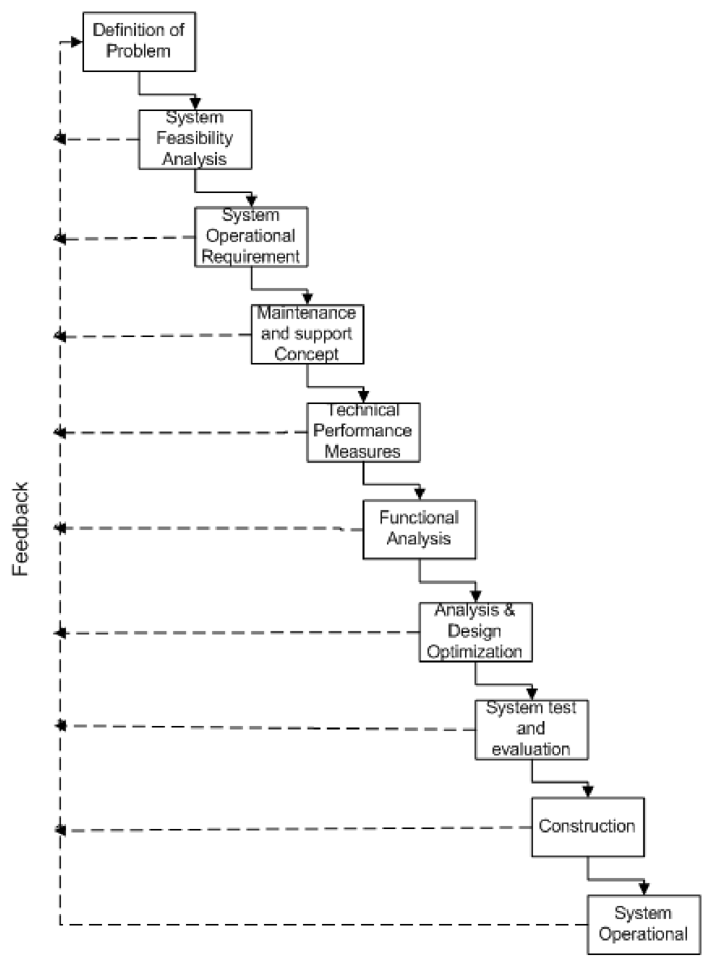

Figure 8 System Engineering Process (Blanchard, 2008)

System Requirements

The overreaching goal of this project is to determine the feasibility of a digester for Heybeli Island given the limited resources and location problems that the island presents. The customer for this project will be the local residents on the island that live there year round. The primary function of the digester will provide an alternative means of waste disposal other than either shipping it off the island or burning the waste, both of which are currently being done. Shipping large amounts of the manure off the island is costly for the local government, while burning the waste is extremely harmful to the environment along with creating unpleasant odors that detract from the tourist appeal. The secondary functions will be using the gas from the methane production in a beneficial way to the community. In addition the use of the fertilizer yield of the digester will be examined; examples of uses for the fertilizer are mushroom production on the island or shipping it to the mainland to sell.

Since this is an island and the acquisition of resources for problems that might arise would have an increased difficulty it's important for the digester to have a long life cycle in order to reduce the necessity of acquiring resources off the island. In addition there will be little technical expertise on the island for the use of digesters, so their needs to be a low skill requirement for operation and maintenance to insure the best use of the product for the customer.

System Operational Requirements

Having defined the basic need and the selection of a feasible technical design approach in the plug flow digester, it is necessary to complete a more comprehensive description of the anticipated system operational requirements. This will constitute the baseline for which all subsequent system design and development effort will be evaluated against.

One of the first and most important questions to look at is where is the system going to accomplish its mission on the island and for how long. Since the volume of animal waste is significant, the possibility of multiple small digesters instead of a single large scale community digester needs to be examined. With the access to resources for maintenance and small economic resources inherent for the local population, a greater priority is placed on an extensive life cycle for all major components of the system.

Performance Operational Requirements

The goals of the system were indentified previously in the primary and two secondary functions of the system which are waste disposal, the development of a gas allocation system, and development of the fertilizer use respectively. The digester will need to be able to accommodate at minimum 4038 liters of total slurry input. There is a 0.8 to 1 (Nijaguna, 2002) ratio of water to animal waste which forms the slurry that is required to create the water to solid concentration that promotes methane production. Figure 3 show's the total waste produced per day and the total number of horses on the island which was used to calculate the total input requirement. There is assuredly going to be less than 100% efficiency in getting all the animal waste on the island to the digester, but by keeping the original number we can accommodate future fluctuations in the number of horses.

Table 1: Digester Input

Waste Produced Per Horse (kg/day)	20.4
Number of Horses	100
Total Manure (kg/day)	2040
Total Volume (liters)	4038

A foundational requirement of the gas use selection of the digester is focused on the digester coming approximately close to breaking even within the life cycle of the digester with the total cost allocation. The gas that is produced can possibly be used to offset the local stables energy bill along with other public locations that will be a benefit to the entire community. In addition, if the use of the gas is to be for heating and cooking, the displacement cost of what currently is being paid by the inhabitants has to be equivalent to the total cost of the digester, or additionally justified by environmental and social offsets.

Utilization Requirement

The demands of the user from the digester will require a daily loading of the waste into the mixing tank. The digester will require a more extensive time demand on the operator once every four months for extra maintenance, which requires on average approximately two hours per week (Kossmann, 2007). Once every three years the digester will need to have further maintenance and a thorough cleaning. This maintenance downtime would require a complete day of labor. The end result would be the digester in operation throughout the year with a day taken out for extensive maintenance. An uptime of 99% or greater will be a target for this design.

Environmental

Temperature is one of the major factors affecting the growth of bacteria responsible for biogas production. Biogas production can occur anywhere between 4° to 68°C

(AgSTAR Handbook). As the temperature increases, the gas production rate also increases, up to a limit.

The environment for which this digester will be operating in is Heybeli Island of Turkey which has an average temperature range from 2.8 to 28.5 °C with the record low and high being -16.1 to 40.5 °C. The daily mean for the year on the island is 14.3 °C. The humidity on the island has a yearly mean of 72% which varies no more than 5% either way throughout the year.

Technical Performance Measures

With the development of system operational requirements and the maintenance support concept the prioritization of these requirements needs to be formed to best accomplish the desired goal. The objectives tree in Figure **9** gives a visual aid in facilitating this prioritization process.

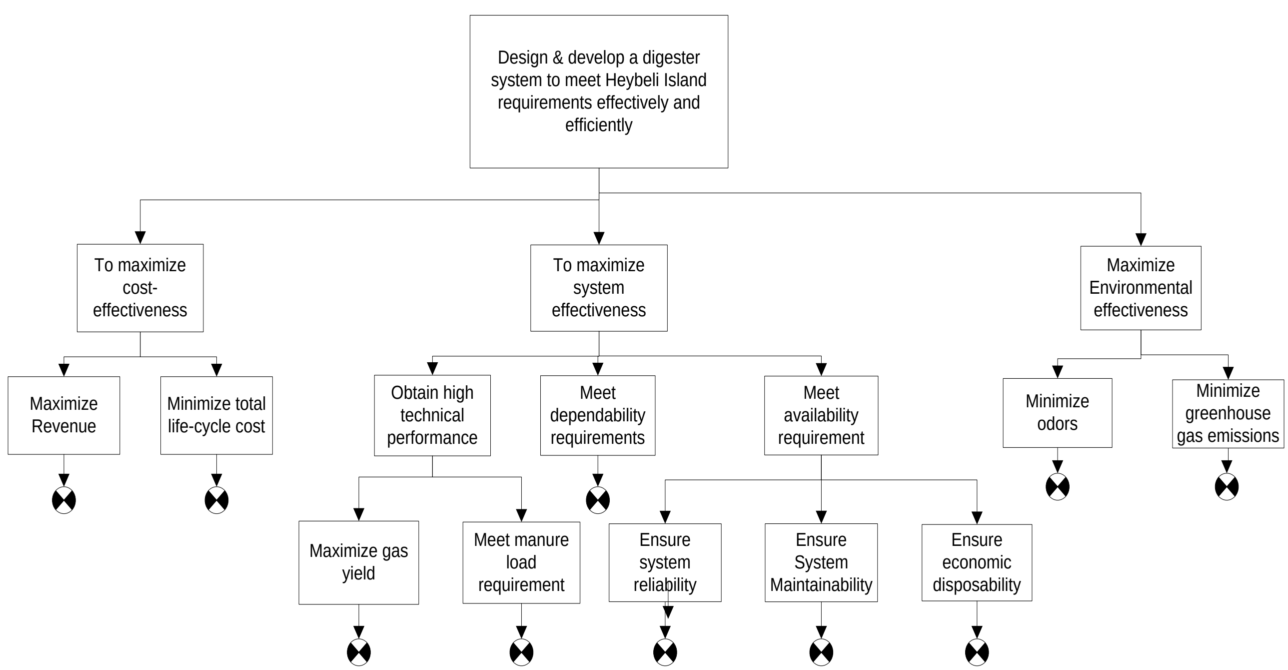

Figure 9 Objectives Tree

Constraints

The assumptions and general constraints that this project will be working under will be evaluated in this section.

Economic Constraint

Digester efficiency is a major concern for this project but the System Engineering and Supply Chain analysis has implicated bigger issues. Thus, the foremost concern of this project is the cost of the final product to the Heybeli community.

Since Heybeli is an island, this makes getting any items to the island a more cumbersome and expensive process, since everything has to be shipped to the island by ferry from mainland Turkey.

Waste Constraint

The occurrence of daily production of manure is essential for the digester to continue in operation. Thus, in addition to the fact that according to the community on the island, they don't plan on changing their ban on motor vehicles, the assumption can be made that they will be relying on horse power and horse transportation for the foreseeable future. This project is being approached under the assumption that the island will have a large horse population and the ability to collect and transport that manure to the digester for the next 15 years which is the life cycle of the project.

As discussed in the operational requirements the system will need to have the capacity of over 4000 Liters of slurry per day if to meet capacity for the island. With the production of the manure being continuous and stable, the preferred method for the digester input would be for the daily loadings. In addition specific digesters require different total solid concentration, with horse manure being in the range of the 11%-

12% total solid concentration (Oechsner, 2004). Figure 5 shows the recommended digester type for varying percentages of total solid concentration.

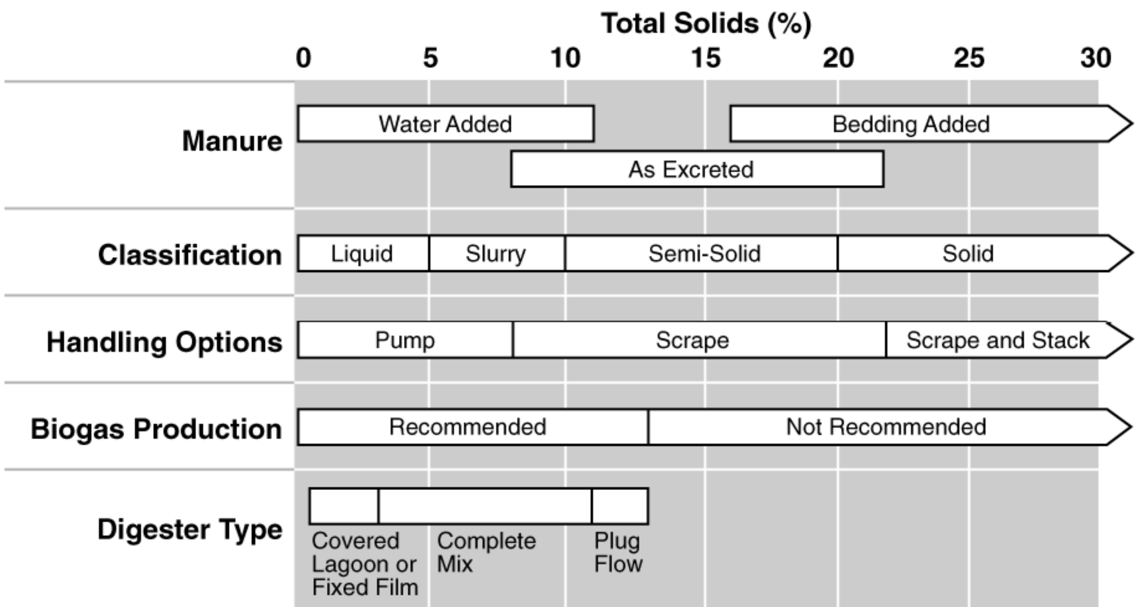

Figure 10 Manure Characteristics for specific digester types (AgSTAR)

Feasibility Analysis

In considering different design approaches, alternative technologies of digester designs are investigated. There are several potential digester design approaches that can be used in this project. While some are more unique than others, it is important to not limit the potential solution at this point. After exploring each solution individually through a literature review, the alternatives are assessed using a matrix typically used in project management. Based on weighted criteria, the different system designs can be evaluated more objectively and the best solution can be found. This is selecting the overall of the design not selecting the specific components hardware, software, facilities, etc.

A top level design of the digester needs to be selected before an analysis can be evaluated for the gas use allocation and relative size and location of the digester. Below are top level descriptions of each design alternative and the matrix evaluation tool.

1. Batch Digester

Batch digesters provide simple construction and easy operation with low skill requirements to operate. But it has varying gas production time and requires gas storage. As the name sounds, batch digesters require large input values at a single time and after that it must wait while that batch is being processed in the digester. Once the batch is finished the process can be repeated by adding another batch of animal waste (Nijaguna, 2002).

2. Fixed Dome Digester

The fixed dome digester has a simple construction, with readily available materials at low cost. The fixed dome has relatively high pressure gas supply which could be useful if going to put the gas into pressurized tanks to be used later. Fixed dome digesters are generally made underground which will provide stable temperature to the digester year round. Though tradeoffs of this design is requires large structural strength in construction and low gas yields from the low concentration feeds.

3. Floating Dome Digester

Gas yield is constant with stable gas pressure in the floating dome digester It has a higher yield than the fixed dome digester but its temperature is highly dependent on the weather which results in an unstable temperature in non tropic regions(Nijaguna, 2002). In addition it is less complicated in installation than the fixed dome digester. Disadvantages to this design are in the high total cost of materials along with the high heat loss and a short life cycle.

4. Lagoon Digester

Lagoon digesters require the largest land requirement of all the digesters that are being considered in this project. In addition to this they are also the hardest to maintain at the optimal temperature range for the anaerobic process for methane production to occur. Advantages to this design are the high gas yield it offers when it’s at its Mesophilic temperature.

5. Plug Flow Digester

The Plug Flow digester allows high total solids loading while maintain high efficiencies which is especially good in this instance with the use of horse manure. Plug flow provides high gas yields while maintaining relatively simple construction. It also can utilize passive solar heating. Downfalls of the plug flow design are the low gas delivery pressure ad relatively high land requirement compared to all other designs other than lagoon.

Design Alternative Selection

Table 2: Alternative Design Matrix

Requirements	Relative Importance (1 -100)	Single Project Impact Definitions	Score 1	Score 2	Score 3	Score 4	Score 5	Weighted Score 1	Weighted Score 2	Weighted Score 3	Weighted Score 4	Weighted Score 5
Biogas Yield	100	0 ≤ Low Potential 1 ≥ Medium Potential 2 ≥ High Potential	0	0	1	2	2	0	0	100	200	200
Budget/Maintenance	100	0 ≤ High Cost 1 ≥ Medium Cost 2 ≥ Low Cost	2	1	0.5	0	1.5	200	100	50	0	150
Temperature	70	0 ≤ High Requirement 1 ≥ Medium Requirement 2 ≥ Low Requirement	0.5	1.5	0.5	0	0.5	35	105	35	0	35
Life Cycle	90	0 ≤ No Potential 1 ≥ Low Potential 2 ≥ High Potential	1	2	0.5	1	1.5	90	180	45	90	135
Land Space Requirement	40	0 ≤ High Requirement 1 ≥ Medium Requirement 2 ≥ Low Requirement	1.5	1.5	1	0	0	60	60	40	0	0
Gas Output Pressure	50	0 ≤ No Potential 1 ≥ Low Potential 2 ≥ High Potential	0	1.5	1	1.5	0.5	0	75	50	75	25
Waste Input Volume	60	0 ≤ Low Potential 1 ≥ Medium Potential 2 ≥ High Potential	0	1	1	2	2	0	60	60	120	120
Maintenance Time	80	0 ≤ High Requirement 1 ≥ Medium Requirement 2 ≥ Low Requirement	0	1.5	1.5	1.5	1.5	0	120	120	120	120
Construction Complexity	70	0 < High Complexity 1 > Medium Complexity 2 > Low Complexity	2	1	1	0.5	2	140	70	70	35	140
							Total Weighted Score	525	770	570	640	925
							Priority	5	2	4	3	1

Each alternative was scored based on their ability to meet the requirements and multiplied by the relative weight to create the weighted score. The weighted score for each alternative was summed, with the highest total weighted score representing the best alternative. As can be seen from the table the Plug Flow design was the chosen design for this project.

Design of System Alternatives

Once the requirements for a system have been established, synthesis can be applied to the design to create several alternatives (Blanchard, 2008). The first step is to design the goals of the analysis. The goal for this step is to generate and evaluate different system designs of the specified type of digester. The second step is to select evaluation parameters. The evaluation parameters for this project are the effective management of the waste to benefit the local people, environment and to earn a profit. For step 3, identifying data needs means that data needs to be generated that can evaluate each of the parameters. This step will be explained in more detail in the methodology section. Finally, a model of evaluation needs to be decided upon. For our project, the triple bottom line places equal value on the overall benefit on the local population, the environment and the net profit (Blanchard, 2008).

Once the plug flow model has been chosen for the digester, a variety of other alternatives arise from the process of synthesis that can be evaluated using the triple bottom line using the specific plug flow design. Not all of the digester designs will have a financial benefit; some of the alternatives will simply offer a way of managing the waste in a more environmentally friendly way with respect to gas emissions, water pollution and health concerns with the people who work in the stables and with the horses or live near the manure pile.

All alternatives will be evaluated in comparison with the current system in place. Each horse that is used for carriage pulling during the day has a pouch that captures the manure from the horse upon release. At the end of the day, that manure is then piled near the stables where the horses are kept at night. The manure is toxic, containing different gases which, in some places on the mound will ignite and slowly smolder. After a certain period of time, the local government arranges for the manure to be transported off the island to the main land where the manure is to be disposed of. The exact details of this process were most likely left intentionally vague on the part of the local government. At night some of the locals who tend to the horses will burn the manure for heating. Furthermore, the current energy use for the majority of the local community is a mix between propane, a fossil fuel, and wood collected from the forest area on the western side of the island. Burning fossil fuels is bad for the environment and is not sustainable. The use of wood contributes to deforestation for the local forest and the smoke is harmful for the woman and children who inhale.

The current lack of a waste management system is bad for the environment and the people who deal with the horses. The waste pile pollutes the local water and releases methane, which is twenty three times more harmful than carbon dioxide, into the air (Kossmann, 2004). Flies and other vermin that are attracted to the manure pile can carry diseases. Eye infections and respiratory problems are likely for those that work near the burning manure pile and for those that burn the manure for heat. Gastrointestinal diseases including schistosomaisis, ancyclostomaisis and dysentery are the main diseases most commonly found in impoverished areas where the local people handle animal fecal matter (Kossmann, 2004). Finally, the odor of the manure pile is unpleasant for the locals and something that needs to be eliminated on an island where the majority of the economy is based on tourism.

Difficulties evaluating alternatives

Many different difficulties arise when evaluating the different alternatives for the design of a digester and most of those are due to the assumptions that were necessary to make to complete this project. At the beginning of this project, the number of horses was stated to be little more than ten. This would necessitate a relatively simple design for the digester that could cost as low as a couple hundred US dollars. However, after more direct contact with the local government on the island that estimated number increased to about one hundred horses. With this large jump in total horses, the amount of manure that would need to be handled daily was multiplied by a factor of ten. This amount of manure justifies a much more technical digester that would require precise engineering in the design of the heating, gas handling and effluent storage systems.

To obtain an accurate forecast for gas production, it is vital to know the amount of manure each horse supplies and the average volatile solids concentration of their manure. The theoretical quantity of methane available per day is directly proportional to the total kilograms of volatile solid produced per horse per day. Before the implementation of any digester that would use gas as an energy source, accurate tests would need to be conducted to determine these factors. The temperature the digester can be held at also affects the gas output. Most of the alternatives provide equipment that would minimize the effect of the climate outside of the digester.

The conversion of the Turkish currency, the Turkish Lira (TRY), to the US dollar provides further complication to the financial calculation. The conversion changes drastically in comparison with the values for fertilizer and biogas. During the month of February, 2010, the exchange rate was as low as 1.48 Turkish Lira per dollar on February 1, to as high as 1.55 on February 23. If the annual benefit of the project was worth 30,000 TRY, the conversion could differ by as much as 1,000 USD per year. The value decided upon in this project was the average exchange rate for the last year, 1.52 TRY to 1 USD. See the graph below for the average monthly exchange rates for the Turkish Lira to the US dollar for the past year (Exchange-Rates.org, 2010).

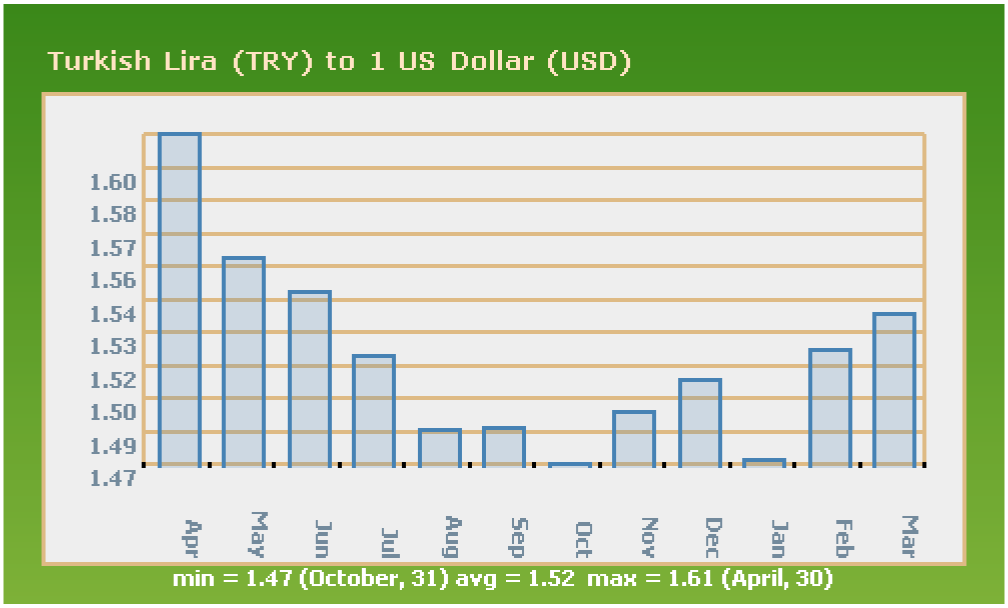

Figure 11 Average Monthly Exchange Rates

The final difficulty in evaluating the profit potential for each digest is determining the worth of the output biogas and fertilizer. The best way of measuring the value of the biogas is determining the value of different sources of energy the biogas would be displacing. If the final design alternative determined that the best use of the biogas would be to use as generator to convert the gas into electricity, and the biogas would therefore be valued by the equivalent value of the electricity it produces in Turkey where it will be used. The problem arises, however, when the gas would be used to replace wood that is currently being gathered from the nearby forest area. The cost of wood to the local population is only the time it takes them to gather it, which is still could involve a mile of walking and carrying the wood. There are environmental and health benefits in switching from wood to biogas, but it would be impossible to determine the direct effect of switching to biogas on the health condition of local people by simply calculating the difference in medical bills (Kossmann, 2004).

This same logic follows with the value of the fertilizer which is calculated based on the levels of nitrogen, phosphorous and potassium present in the manure. These numbers are impossible to estimate without tests done on the fertilizer. This project assumed that the fertilizer would be equivalent to the average current price of fertilizer in

Turkey. In most cases, digester effluent that is used for fertilizer has shown better results than the standard available fertilizers, sometimes resulting in yield increases well over ten percent.

Therefore, the output values depend greatly on the allocation of the gas and fertilizer, which in most cases will be divided for multiple uses. Also, it is essential to do tests on the manure to calculate the actual gas yield which will replace the current estimates used in this project. Capital costs on the gas allocation and heating systems was not readily available and if these systems are included in the chosen design alternative, environmental engineering consultation will be used to generate actual cost for equipment designed specifically for the waste management for the island of Heybeli, Turkey. Current estimates for the mentioned systems were based on the costs for digester systems that dealt with similar quantities of manure and similar manure types in locations with similar climate conditions.

Fully allocated cost

Once the design of the digester has been chosen a more inclusive estimation is needed to forecast the overall cost and benefits of the design. Costs can be broken down into three different categories: capital costs, operation costs, and overhead costs. The capital cost will include the material cost including shipping, taxes, and construction cost. Operation Costs will occur yearly throughout the life of the digester. These costs will include labor wages, maintenance costs, utility costs and cleaning costs. The final category is overhead costs. This cost includes engineering design, and management costs.

Methodology

This section contains the methodology of the project, with pertinent information based on researched and communication with suppliers and business worldwide. Information was used to analyze different alternatives based on the triple bottom line evaluation method. Further, investigation was then made into the chosen alternative system.

Total Gas Yield

The first thing that needs to be determined is the total amount of volatile solids, which is what methane is produced from during anaerobic digestion. With the given data from the island of 100 horses and finding that the average amount produced per day by a horse is 3.4 kg of total volatile solid the total mass can be found (NIjaguna, 2002). The total volatile solid was found In Table 3 to be 272,000 grams.

Table 3: Total Solid Calculation

Volatile Solid per horse (kg)	3.4
Total Horses	100
Total Volatile Solid (kg)	340
80% Efficiency	272
Convert to Grams (g)	272000

Using the volatile solid number gives a theoretical gas production value of 150,633 L_CH_4/day. The equation that was used can be seen in below, and was found in <u>Biogas Technology</u> by B.T. Nijaguna.

$$\left(\frac{272{,}000\ \text{VS}}{\text{day}}\right)\left(\frac{1.42gCOD}{gVS}\right)\left(\frac{0.39L\_CH_4}{gCOD}\right)=150633.6\,{}^{L\_CH_4}\!/_{day}$$

Given that the methane produced is $150{,}633^{L\_CH}{}_4/_{day}$ the total biogas can be found by dividing this number by 0.7 since there is usually a 70% methane concentration in biogas (Dewan, 2004). After dividing the methane by 0.7 it gives us 215,191L of biogas. Using that number we can determine the theoretical Kilowatt-hour production using the biogas through a generator.

$$\left(\frac{215{,}191L\_CH_4}{\text{day}}\right)\left(\frac{0.001\_m3}{L}\right)\left(\frac{2KW}{m3}\right) = 430.382 Kilowatt - day$$

Digester Alternatives

When deciding upon the most optimal digester system, multiple alternatives were evaluated. Internal Rate of Return (IRR) and payback were used to determine the overall financial benefit of each alternative using cost estimations. The life span of the digester is assumed to be 15 years, fifteen to twenty years is a conservative estimate for the full life of the digester assuming proper maintenance. There is a large difference for these designs between the value of the outputs and the expected monetary returns. In terms of worth, the gas is valued by the equivalent energy output. One cubic meter of methane gas is equivalent to 0.24 cubic meters of propane. Therefore the value of biogas is worth approximately one fourth the value of propane per cubic meter, but that does not mean that biogas will be sold for a fourth the cost of propane per cubic meter. In another example, one cubic meter of gas is equivalent to 1.3 kilograms of wood (Kossmann, 2004). Since wood has no monetary value to the local population that does not mean that biogas is valued at nothing. For analysis purposes, the biogas will cost will be used in the financial evaluation and the biogas worth will be used in the benefit on the local community

The total benefit for the environment will be measured by kilograms of CO2 prevented from leaving the atmosphere and the replacement of unsustainable energy sources. The overall benefit for the local community is harder to quantify and therefore will be more difficult in evaluating differing alternatives as mentioned above. Each alternative will be evaluated on how well it improves the current living conditions specifically with respect to the health conditions of the people that handle the manure, health conditions of the local impoverished population that live in the vicinity of the horse stables and manure pile and the overall reduction of odors.

Table 4: Alternative Systems Overview

	Systems				
	1	2	3	4	5
Total Capital Cost Estimate (USD)	\$984,000	\$159,000	\$47,000	\$19,000	\$10,000
Yearly Benefits (USD)	\$18,000	\$26,000	(\$3,200)	(\$1,500)	\$0
Captured Kg of CO2	120,000	120,000	120,000	50,000	24,000
Ranking for Effect on community (1 highest)	1	2	4	5	3

System 1: Full Scale Plug Flow Digester for Gas Distribution

A system that would allow for the gas to be pressurized into individual containers and then distributed at a cost low enough that the majority of the local population could use the biogas for cooking and for heating would be ideal. A sustainable business, similar to what Muhammad Yunus developed, could be implemented and run by the local population, capturing and then distributing the gas (Yunus, 2007). This system would fully manage the horse waste, provide financial benefits to the local community, and displace their current sources of energy. The problem with this system is the cost of the gas handling system. In order to be pressurized, the gas needs to be scrubbed, purified, and then dropped to low temperatures to condense the gas into a liquid. The cost of the system was estimated a little less than one million US dollars with about 900,000 US dollars solely devoted to the pressurization system. This dollar amount was by far the largest of all the alternatives evaluated and the capital cost would be far greater than the most optimistic monetary returns. (Buhrmaster, 2009)

This system does have the greatest potential benefit to the environment and the community. All of the gas can be directly allocated to the local impoverished community replacing the current sources of energy that are not sustainable. The estimated kilograms of CO_2 saved, 120,000 kilograms, could potentially increase given the savings from methane use over their current energy use of wood and propane. These numbers were not incorporated because it is impossible to know the quantities of wood and propane currently being consumed. Having energy immediately available decreases wood gathering time and could be used for light after the sun goes down. This would give the local women and children, those who would be doing the cooking and gathering, more time towards other activities including education.

System 2: Full Scale Plug Flow Digester Utilizing Biogas Generator

System 2 is a modified form of the previous alternative. A full scale digester would include a manure collection system, a digester tank, a gas handling system and an effluent storage system (Brewer, 2001). For this particular alternative, the gas would be piped to a biogas generator specifically designed to convert methane rich gas into electricity. Some piping, including a gas pump and meter, are necessary to regulate the flow. This type of gas handling system, which counts for a majority of the overall capital investment, would cost between 75,000 and 105,000 US dollars depending on the capacity of the biogas generator. For the purposes of Heybeli Island, the gas output would fit a generator on the lower side of that pricing range. One of the extra benefits of using the generator is installing the generator cooling system as the source of the digester heating system; the water will flow through the generator to and then to the digester. (Goodrich, 2005)

The generator takes the methane gas and burns it, converting the biogas into CO_2 and water. Methane is twenty three times more harmful to the environment than CO_2, so while there is output of CO_2 into the atmosphere, the output is a mere fraction of the harmful methane gas that would be released into the environment with the current manure pile system (Kossmann, 2004). This system provides all the same environmental benefits of system 1 given that the electricity is used to replace the current sources of energy. Many of the houses have power from electricity and some of the lower income houses even have refrigerators. However, it is not certain if all the lower income areas have access to power. Converting the gas into electricity gives the distributer the flexibility to use in any way that is best ensuring that the will always be a use for the energy which may not have been the case with System 1. The local government is interested in this project and will most likely be willing to finance a larger portion if they can have more input on the use of the gas.

There is technology on fuel cells that has just recently been applied to digester systems; however, these advancements are still experimental and very expensive. When implementing this system, fuel cell technology should be investigated to know if it has surpassed biogas generators in efficiency (Buhrmaster, 2009).

System 3: Simple Plug Flow Digester

This design focuses largely on the management of the waste and less on the value of the biogas. A simple plug flow digester would consist of a large tank that would handle the manure; however all the gas would be used to heat the digester system and the excess gas would be flared. Because this system would be less efficient, less gas would be produced and removed from the waste. This translates into lower environmental benefits, but the local people will still benefit from a cleaner waste handling system. They simply will not receive any benefits from using the extracted gas as an energy source. The flaring of gas is common for systems that are too small to produce enough gas to justify a gas handling system or that do not have the funds to invest in the gas handling system. If the gas is being flared then the annual net benefit is going to be in the red, which makes this option less desirable. In many of these latter cases, gas handling systems are planned to be implemented at a later date when funding becomes available. This could be a similar approach to this digester for Heybeli Island if funding is limiting the implementation of the project.

System 4: Scaled Down Plug Flow Digester

System 4 entails a small plug flow digester that would only handle a portion of the manure. This system would be cost effective for the manure it handled, but would only solve a portion of the problem. This option would be the least expensive alternative, yet still not cheap considering that the gas would be best allocated to heat the digester and possibly the stable, depending on the output, where the horses are kept which would not return any profit. This option would be better viewed as an experimental run to help evaluate the placement of a long term digester with accurate information.

System 5: Family Sized Plug Flow Digesters

This last system was included because a vast majority of the current digesters are individual family sized units in the poorer regions in China and India. (Nijaguna, 2002) System would have a small digester next to each house that would pump the gas directly into the house to be used for cooking and heating. However, the fact that the horses are not kept near the houses means that the manure would need to be transported and distributed to each individual house. The entire system would be an inefficient use of gas and time. In order to finance this type of venture, some sort of contract would be needed for each house promising annual payments. The environmental benefits and community effect is lower simply because the efficiency of the system would not allow for the maximum yield of gas.

Fully Allocated Cost of System 2

The table below shows a detailed estimate of the entire project in US dollars. The parts that would be easily purchased in Turkey were assumed to be purchased there. The project places a high value of supporting the local community which includes the local economy. All construction tools, cement, rebar and piping was determined to be purchased either directly on the island of Heybeli or in Istanbul. The rest will be shipped from the United States from suppliers either in Connecticut or Baltimore depending on where the parts will be purchased. Exact quotes on the generator and gas handling system were not available and were estimated by comparing the proposed digester system to other already constructed digesters.

The current system on the island already has a method for collecting the manure and was assumed to stay the same. Labor costs for collection were included into the labor costs.

To calculate the cost of the digester tank, the total volume must first be calculated. The basic equation for the volume is the amount added per day multiplied by the time it takes the manure to move through the digester called the Hydraulic Retention Time (HRT). The best HRT for a plug flow digester is thirty days. The total waste per horse was assumed to be six gallons of manure. This assumes that all potential waste is gathered. When you add a .8 to 1 water ratio the equation is:

6 gallons x 100 horses x 1.8 x 30 days = 32400 gallons or 122.634 cubic meters The dimensions for a tank this size would be 48'long by 12' wide by 8' deep. With these dimensions the total cement can be calculated along with the necessary requirements for rebar. (Brewer, 2001)

The price for the gas meter is included in the price for the gas pump.

The main cost is due to the biogas generator. The estimates for the generator, cooling system and installation range from $75,000 to $115,000. This project would only need a 30 KW micro turbine, which puts the cost on the lower side of the spectrum. (Goodrich, 2005)

Engineering costs are standard for projects of this magnitude and estimated at $30,000. This cost is incurred during the calculations for the gas handling system and generator. (Lamb, 2001)

The digester will require on average two hours of maintenance per week and 4 hours of operation per day. The local living wage in US dollars is $2.50 per hour. The digester also needs to be flushed out once between years three and five and again every five to eight years after that. Maintenance costs were assumed to be five percent of the total initial capital cost.

The digester would be built on government property and is assumed to be free of charge.

Table 5: Fully Allocated Cost

Fully Allocated Cost of System 2		Projected Values
Capital Costs	**Mix Tank/ Manure Collection**	
	Manure Pump	$8,000.00
	Piping	$1,000.00
	Collection	$0.00
	Subtotal	$9,000.00
	Digester Tank	
	Cement Work	$6,000.00
	Cement	$26,305.00
	Rebar	$984.00
	Subtotal	$33,289.00
	Energy Conversion System	
	Gas Pipes	$1,200.00
	Gas Pump	$6,000.00
	Gas Meter	$0.00
	Generator	$78,000.00
	Subtotal	$85,200.00
Overhead	Engineering	$30,000.00
	Maintenance/ Repair Costs	$5,924.45
	Shipping Costs	$10,000
Operational Cost (in years)	Labor Hours	$3,250.00
	Water usage	$916.00
	Land	$0.00
	Subtotal	$4,166.00
Initial Capital Investment		$168,579.45
Yearly Cost		$4,166.00

Manure Allocation

The economic analysis for manure handling was separated for multiple reasons mostly due to the unknowns of the current situation. The local government is transporting the manure of the island, but it is unknown how often, and in what quantities. Once the manure is on the main land the question is do they sell it, dump it, or pay someone else to handle it? Finally it is impossible to determine the levels of the different nutrients in the manure that would determine the value of the fertilizer byproduct of the digester.

The current demand for fertilizer in Turkey is very high. Approximately twelve percent of Turkey's GDP is from agriculture (Tatlidil, 2009). A look at the map shows the dominant crop area in Turkey.

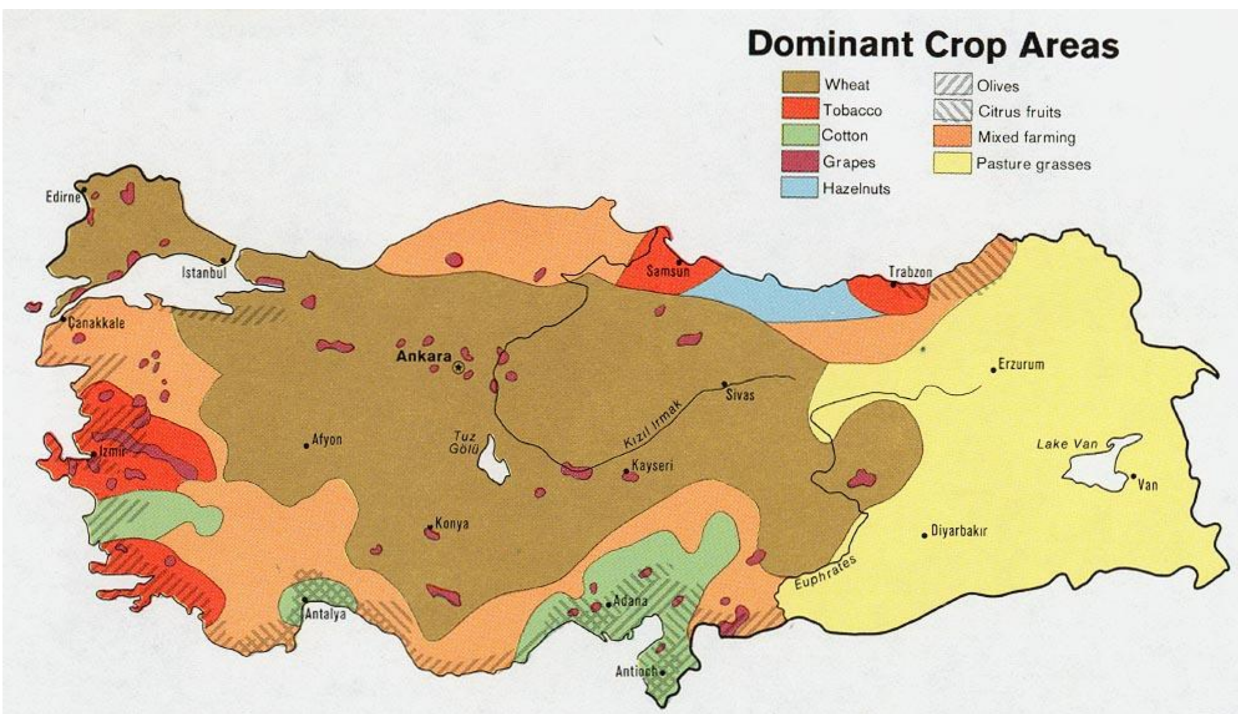

Figure 12: Dominate Crop Area's in Turkey

The digester on Heybeli, which is located in the Marmara sea directly below Istanbul, would produce a little less than one ton of bio-fertilizer per day. A model should be developed for transporting the manure off the island to the main land for sale.

Optimally, a partner could be found with whom a long term contract could be developed. Language barriers provide difficulties for fully developing a model. The excerpt below states the current prices for fertilizer in Turkey:

> *"Nur Özkan'ın verdiği bilgiye göre kompoze gübrelerden **20.20** taban gübresi 10 Kasım 2009'da **tonu** 460 liradan satılırken 10 Şubat 2010'da **650 liraya** yükseldi. Üç aylık sürede artış oranı yüzde 41 oldu.*
> ***15-15-15** taban gübresinin fiyatı aynı dönemde yüzde 18.5 oranında artarak **tonu** 650 liradan **770** liraya çıktı.*
> *DAP(18-46) gübresinin fiyatı ise 670 liradan yüzde 37'lik artışla **920** lira oldu.*
> *Azotlu gübrelerden ürenin fiyatı yüzde 16 oranında artışla tonu 585 liradan 680 liraya yükseldi.*
> *Amonyum sülfat gübresinde yüzde 45.5 oranında artış oldu. 10 Kasım'da tonu 275 lira olan amonyum sülfatın tonu **400** liraya çıktı.*
> *33 Nitrat gübrenin tonu 440 liradan yüzde 32 oranında artışla **580** liraya, 26 nitrat ise 420 liradan yüzde 11 artışla **470** liraya çıkarıldı."*

With the help of Dr. Alptekin, an estimation of 600 TRY per ton was found to be used for the price of fertilizer in Turkey useful in some basic estimations.

$$\left(\frac{0.94\ Tons\ of\ Bio-Fertilizer}{Day}\right) \times \left(\frac{365\ Days}{Year}\right) \times \left(\frac{600\ TRY}{Tons\ of\ Bio-Fertilizer}\right) \approx \frac{200{,}000\ TRY}{Year}$$

200,000 TRY is the equivalent of 135,000 US dollars per year. Cost factors including shipping, packaging, tax, and labor hours still need to be factored in to determine the potential profit per year. This amount was not factored in because it could not be compared to the current system and the local government/school is interested in starting a mushroom venture utilizing the fertilizer. A sustainable business plan could be developed to analyze this possibility. There is obvious potential, but at this stage in the project more investigation needs to be done on the manure, mushroom venture, and cost of sending the manure over sea.

Results

Once the estimates for each of the alternatives have been generated, the different alternatives can be contrasted. The financial profit is the clearest evaluation criteria to compare. Only two of the alternatives, Systems 1 and System 2, return a yearly gross profit and System 1 has a breakeven point, 54.6 years, after the assumed life span of the digester. Refer to Table 4: Alternative Systems Overview. The only profitable alternative is System 2 with a breakeven point of 7.4 years. Using engineering economics, the IRR can be calculated using the following equation (Newnan, 2009):

$$Total\ Cost = \ Annual\ Profit\ \times (P\ given\ A, i, years)$$

$$\$168{,}579 = \ 22722\ \times (7.4\ i, 15\ years)$$

Using a chart from the engineering economics text, the IRR can be determined to be 10.5% which is a desirable return compared to other market investments. From a financial perspective, System 3, 4 and 5 all are better investments simply because they have a larger, less negative present worth.

Systems 1, 2 and 3 all capture the maximum amount of gas because they are designed to manage all of the horse manure at the optimum temperature. The other designs either don't handle all of the gas or will most likely not be kept at the optimum temperature range due to lack of heating and upkeep by local untrained families. System 1 and System 2 provide additional benefits because they provide an energy source that could replace current fossil fuels that release greenhouse gases when consumed. They also would combat local deforestation if the individual energy output was replacing any wood consumption.

The final criteria is the most difficult to compare because it is impossible to quantify the different effects of the system on the local population. However, the effect of the digester on the local community is the criteria with the highest priority because that was the initial reason for the project. System 4 does not handle all of the horse manure and unless, plans were made to expand that alternative into multiple phases, it should be deemed undesirable. The rest of the systems handle all of the manure, however System 5 would need more transportation and more time handling the harmful waste. Systems 1 and 2 offer the greatest benefits to the local island with System 1 being valued slightly higher because it ensures that the gas will be given to the local community whereas System 2 is allowing the local government to have a say in the allocation of the gas.

After analyzing all the conditions, System 2 rates as the top option when using profit as the criteria and rates as a close second in the evaluation of the effects on the local community and global climate. System 1 offers the highest value in the effects on the population of Heybeli and the environment however, until the capital cost for the project is drastically reduced, System 2 should be valued as the best alternative.

The fully allocated cost analysis of System 2 details all of the possible cost. The potential exists to decrease this cost if more technical expertise was gained on the system design requirements. With enough expertise, the engineering dollar amount could be avoided making the profit even more profitable.

Grant requests are currently being sent for funding are they are many other options like carbon credits that could alleviate portions of the initial capital investment.

Conclusion

The best system for the people of Heybeli Island involves the use of a large scale Plug Flow Digester. This digester makes use of the output gas to run a generator, which in turn is used to produce electricity. This design combines high return on investment along with improving the environment and social benefit on the island. The payback for this selection is approximately seven and a half years with an IRR of 10.5%.

The original objective for this project was to select a digester design that would provide a waste management system along with a positive environmental and social impact within a reasonable budget. All in all, we feel that we accomplished this broad goal by analyzing all aspects of the System Engineering opportunities and limitations presented in Heybeli Island Turkey.

On a technical level, the project has taught us a lot about System Engineering processes and functions, economic analyses, and the possibilities of digester energy technology. This project has reinforced a desire to apply Industrial Engineering background to improve the livelihood of others. In addition it has shown a further need to use triple bottom-line justification instead of just the cost analysis in choosing solutions to problems.

In hindsight, there are several things that should have been done differently. For, one the time span was not nearly long enough, as the project required communication and information from Turkey which because of the language barrier and the unavailability of the internet on the island greatly slowed down the transfer of information. Additionally, it would have been greatly helpful to have been able to make a trip to Heybeli Island for these activities, since they would have provided direct communication to the stakeholders of the project, first hand observations of the horse logistics, and contact for future questions.

In addition to this project it would be beneficial to test the nutrient content and volatile solid concentration of the animal waste before the final decision on construction of the digester begins. These results would give more accurate predictions for the digester benefits on the local community, the environment and net profit and provide less financial risk for the community.

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